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MECHANICAL COMPONENT HAVING AT LEAST ONE FLUID  
TRANSPORT CIRCUIT AND METHOD FOR DESIGNING SAME  
IN STRATA

5 The invention relates to a mechanical part that includes at least one circuit intended to contain a fluid and to a method for producing said part.

10 The invention is applicable in a very wide range of fields such as, for example, in mechanical engineering (for example for the manufacture of cylinder heads), in printing (for the production of marking ink circuits), or other fields.

15 The invention applies preferably, but not exclusively, to the field of plastics processing and more particularly to the problems posed by the thermal regulation of molding tools (dies or punches).

20 The thermal regulation of an injection molding tool has the function of extracting, to the outside of the tool, the thermal energy provided by the molten thermoplastic. This energy had been given to the thermoplastic by the plasticating screw so as to make 25 the thermoplastic able to conform to the impression. This energy must now be removed from the thermoplastic so that the part can be ejected (without any "distortion" of the molding impression). This extraction takes place under conditions defined 30 beforehand during the design of the part and of the tool.

35 The solution most commonly used in the prior art for carrying out the function of cooling and regulating molding tools consists in producing, in the body of the tool, a series of channels through which a heat-transfer fluid circulates, the nature of the fluid depending on the desired average temperature in the

tool.

To obtain ideally effective regulating channels, it is necessary for the channels to be able to form a layer 5 facing the part, or exactly following its shape, and for them to be separated from this part by as thin a wall as possible. Of course, this solution cannot be achieved for technical reasons and because of the high 10 mechanical stresses generated by the injection molding process.

A similar solution is sometimes obtained by a system of channels of square cross section that approximately follow the shape of the part. This solution is used in 15 special cases and it is known to be used only on simple geometrical shapes (mainly on cylindrical punches), and it gives rise to the problem of sealing between the attached parts, resulting in substantial delays and manufacturing costs.

20 Production of these channels by drilling is the solution most often used - this is the least effective but the simplest solution. Since the holes can be drilled only in a straight line, a whole series of 25 drilling operations is necessary in order to follow the impression as closely as possible. The circuit is then formed by the use of fluidtight plugs, or even the use of external bridging arrangements for the difficult cases, but these are to be avoided as far as possible 30 owing to the risk of their being crushed or broken while the mold is being handled.

35 Insufficient cooling may result either in geometrical precision problems or in excessively long cycle times. In the worst cases, it may be the cause of production shutdowns, during which the mold is left open so as to be regulated by natural convection. Despite all these risks of malfunction, this function of the tool is

still often neglected when designing molds for injection molding. The regulating system is very often designed as the last item, and must be placed between the various ejectors, the guiding column, etc. This is 5 erroneous since this function is the keystone of the injection molding process, as the conditions for cooling the part play an essential role in the level of internal stresses in the injection-molded parts and in the crystallinity of the polymer and therefore in its 10 aging stability and its mechanical properties.

Consequently, the production of the cooling/regulating channels currently represents a major challenge in research on improving performance in plastics 15 processing.

One solution has been proposed in an article in the journal "Emballages Magazine" (January-February 2002, supplement No. 605 "How to optimize the molding of 20 plastics").

This solution entails the production of a first, prototype mold and then its behavior during cooling is observed and recorded. A computer then analyzes the 25 data and deduces therefrom the dimensions and the positions of pins intended to improve the heat exchange. This method leads to the construction of a second mold that is more effective than the first, which includes a set of pins according to a design 30 established by the computer.

This solution is time-consuming and requires prior experimentation.

35 Another solution, proposed in patent application WO 02/22341, consists, in order to increase the heat exchange, in placing, inside a parison, a tubular insert provided with radially disposed pins. The

application of this solution is limited and complicated to implement.

5 The object of the present invention is to alleviate the aforementioned drawbacks of the prior art and to propose to an injection molding tool designer, an entirely novel method for designing and manufacturing the tool and its fluid transport circuit in a fully optimized manner according to the requirements of the 10 part to be produced, by means of the STRATOCONCEPTION® process.

15 This object is achieved by the invention, which consists of a method of producing a mechanical part on the basis of a computer-aided design, of the type comprising:

20 - a preliminary step of breaking down the body of the part into elementary strata;  
- a step of manufacturing the elementary strata;  
- a step of reconstructing the part in its entirety by superposing and assembling the strata,

characterized in that:

25 - the procedure incorporates, during the breaking-down of the part, the breaking-down, into elementary chambers, according to a breakdown associated with that of the part, of at least one fluid transport circuit designed and modeled beforehand, said elementary chambers 30 being produced in the elementary strata of the part during the step of manufacturing the strata;  
- the fluid transport circuit is reconstructed in its entirety during the superposition and 35 assembly of the strata.

As a variant:

- the procedure also incorporates, during the

breaking-down of the part, the breaking-down of an additional isolating circuit into elementary isolating chambers according to a break-down associated with that of the part;

5       - said elementary isolating chambers are produced in the elementary strata of the part during the step of manufacturing the strata;

10      - the isolating circuit is reconstructed during the superposition and assembly of the set of strata.

The invention also relates to a mechanical part of the type comprising a body with at least one fluid transport circuit composed, for example, of channels 15 produced in the body and at a predetermined distance from a heat exchange surface, the circuit being produced by the above methods, and in that the circuit is reconstructed in its entirety during assembly of the strata, based on a succession of elementary chambers 20 that are brought into communication in a fluidtight manner and are provided in at least one portion of the strata in question.

According to certain embodiments, the circuit, after 25 reconstruction, forms, in the body of the part, a set of preferably parallel channels following or copying a molding surface at a predetermined distance from the latter.

30 According to other embodiments, the circuit, after reconstruction, forms, in the body of the part, a layer-shaped chamber.

35 Preferably, the circuit includes means for connection to a regulating device.

According to one embodiment, the part furthermore includes an additional isolating circuit also

reconstructed in its entirety during assembly of the strata, based on a succession of elementary chambers that are brought into communication in a fluidtight manner and are provided in at least one portion of the  
5 strata.

Preferably, the fluid transport circuit is filled with a fluid chosen from the group: heat exchange fluid, thermal insulation fluid, liquid or pulverulent  
10 material, marking fluid.

The present application makes reference to a process called STRATOCONCEPTION (registered trademark) disclosed in patent EP 0 585 502 and to its  
15 improvements FR 2 789 188, FR 2 789 187, FR 2 808 896, FR 2 809 040 and FR 02/80514, the contents of which are fully incorporated here by way of consequence.

The invention will be more clearly understood with the  
20 aid of the description given below with reference to the following appended figures:

- figure 1: a three-dimensional view of a mold according to the prior art with cooling channels;
- 25 - figure 1a: a vertical section of the mold in figure 1a;
- figures 2a and 2b: the principle of breaking down the mold of figure 1a into unitary cells;
- figure 3: a three-dimensional view of a mold  
30 stratified according to the invention and including follower-axis channels for the circulation of a regulating fluid that follows the shape of the molding surface;
- figures 3a, 3b: a vertical section of a mold of figure 3 and its break-down into unitary cells;
- 35 - figure 4: a three-dimensional view of a mold stratified according to the invention and including follower-surface channels for fluid

circulation;

- figures 4a, 4b: a vertical section of a mold of figure 4 and its break-down into unitary cells;
- figure 5: a three-dimensional view of a mold
- 5 stratified according to the invention, which includes a follower layer for the circulation of the regulating fluid, which follows or copies the shape of the molding surface;
- figure 5a: a vertical section of the mold of
- 10 figure 5;
- figure 6: a nonlimiting representation of a follower layer according to the invention;
- figures 7a, 7b: a representation of two successive strata defining the follower layer
- 15 of the previous figure;
- figure 8: a partial representation of a stratum that includes fins for producing a laminar effect in the follower layer, this example not being limiting;
- figure 9: a partial representation of a stratum that includes fins producing a turbulent effect in the follower layer, this example not being limiting;
- figure 10: a unitary thermal cell of a
- 20 regulating follower layer;
- figure 11: a schematic section of a mold stratified according to the invention, which includes isolating follower channels;
- figure 12: a schematic section of a mold
- 25 stratified according to the invention, which includes an isolating follower layer;
- figure 13: a diagram of a method of filling the isolating layer or channels; and
- figure 14: a diagram of a dynamic regulating
- 30 device according to the invention.

Referring firstly to figure 1, this shows the conventional or principle of cooling a mold (1).

Several regulating channels (2) are produced by drilling and/or by the use of plugs, parallel to the molding surface (3) of the mold (1), after the molding tool has been manufactured, and at locations that are 5 generally defined empirically by the mold designer.

Figures 2a and 2b show schematically the basic idea of the invention which consists, so as to make it easier to space the channels and to determine their 10 dimensions, in breaking down, into elementary cells (4), over a given thickness, that region of the mold which surrounds the molding surface (3) which will be in contact with the material to be molded and will consequently be subjected to the heating and cooling 15 stresses during production of the part.

More precisely, figures 2a and 2b show schematically a break-down into unitary thermal cells, applied to one case of the prior art, so as to make it easier for the 20 reader to understand the invention. This break-down is one of the means for making it possible and easier to determine the dimensions of the channels.

According to the inventive concept, each cell is 25 determined so as to be traversed by at most one regulating channel, the positions and the dimensions of the channels being calculated thereafter, depending on the thermal stresses that this region of the mold will have to undergo during the various operations of 30 producing the part (molding, blowing, cooling, demolding, etc.).

The basic concept of the invention consists in designing and producing optimized regulating channels 35 using the STRATOCONCEPTION® process. The design of said channels stems from prior modeling in terms of unitary thermal cells, but this is not limiting.

5 A unitary cell (22) (see figure 10) is formed, over a given thickness, from a part of the mold (22') in contact on one of its faces with the polymer to be cooled, from a part of this polymer (33) and from a unitary chamber (15) in which the fluid circulates.

10 Figures 3, 3a and 3b show a first embodiment of the application of the basic principle to a stratified mold produced using the STRATOCONCEPTION (registered trademark) process or by one of its improvements mentioned in the introduction.

15 According to this process, the mold (1) is produced by using software that breaks said mold down into elementary strata (7), the strata are then produced by micromilling in a plate, the strata then being joined together by superposing them, so that one of the inter-stratum planes (7<sub>i</sub>) is applied against one of the inter-stratum planes of the next stratum (7<sub>i+1</sub>).

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To apply the principle of the invention:

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- each stratum of the mold region concerned in the heat exchange is calculated so as to include a regulating channel (2) that emerges in one of the inter-stratum planes, either the upper plane of a stratum or the lower plane; and
- the channels are dimensioned or designed beforehand according to the requirements of the application and are produced by micromilling during the step of producing the strata, and these are then reconstructed in their entirety on assembling the strata.

30

35 It is therefore the requirements of the part, for example the cycle time, the characteristics of the material, etc. that dictate the dimensions of the channels.

To make it easier to cut the channel (2) by laser or water-jet micromilling in a stratum (7) of the series (7<sub>i</sub>, with i from 1 to n), and because a cross section with a square or rectangular base improves the heat 5 exchange compared with a circular cross section, provision is made, for the embodiment shown in figures 3a and 3b, for there to be at least one channel (2) of square cross section in the stratum or strata (7) of the mold region in question, with a plane bottom 10 (8) parallel to the inter-stratum plane and two side walls (9, 10) perpendicular to the inter-stratum plane (5 or 6) into which said channel (2) emerges. This embodiment is referred to as a "follower axis" embodiment as the longitudinal axis (11) of the channel 15 is located at a predetermined distance (d) from the molding surface (3).

The embodiment shown in figures 4, 4a and 4b provides a channel (2), at least one of the side walls (13, 14) of 20 which is shaped so as to reproduce or copy a portion of the molding surface (3) (this embodiment is referred to as a "follower surface" embodiment), that is to say all the points on said follower side wall (for example, the wall (14)) are located at a distance (d') from the 25 molding surface (3), the bottom (12) and the other side wall (13) remaining parallel and optionally perpendicular, respectively, to the inter-stratum plane (5 or 6).

30 For these embodiments in figures 3a to 4b, the channels are produced by turning the strata over and have a depth less than the thickness of one stratum. Of course, these embodiments are nonlimiting examples and the channels may have other shapes and a depth greater 35 than the thickness of one stratum.

The corners between the walls and the bottom are "broken" so as to limit stress concentrations.

The channels follow the molding surface at a predetermined depth ( $d'$ ) that is constant or that varies depending on the region to be cooled or the cooling requirements.

5

The position of a channel in the interface plane of a stratum ( $7_i$ ) is calculated so that, when the strata ( $7_i$ ) are being stacked, said channel is blocked by the interface plane of the next stratum ( $7_{i+1}$ ) without there ever being an overlap between the two emerging channels.

10

15 The size and cross section of the channels is calculated according to the amount of heat to be removed.

15

According to another embodiment of the principle of the invention shown in figures 5 and 6, the mold (1) includes a fluid circulation layer (15) that follows or 20 copies the shape of the molding surface.

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This follower layer has a predetermined thickness and is bounded by a surface (16) facing the molding surface (3) and a surface (17) facing towards the outside of the mold. The follower layer is predetermined so that all the points of the surface (16) facing the molding surface are at a predetermined distance or depth (D) from said molding surface (3) - this is why said circulation layer has been called a follower layer.

30

This distance (D) is constant or can vary depending on the region to be cooled or the thermal stresses. This fluid layer constitutes a true continuous thermal barrier surrounding the part to be produced.

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A follower layer (15) has been exemplified by a solidified fluid and then shown in isolation in figure 6 with its feed header (18) for the inflow of the regulating fluid and its fluid outlet header (19).

As in the previous illustrative example, the mold is produced by a STRATOCONCEPTION process, and in each stratum involved in the heat exchange a portion of the circuit called the elementary chamber (20) is produced  
5 during the micromilling step, and then the circuit is formed in its entirety after all the strata have been superposed.

The two strata ( $7_i$ ) and ( $7_{i+1}$ ) of the mold that surround  
10 or define the chamber, in which the fluid of the follower layer of figure 6 circulates, have been shown in figures 7a and 7b.

This fluid layer constitutes a true continuous thermal  
15 barrier surrounding the part to be produced.

The corners between the faces and the bottom of the chamber are also broken so as to limit stress concentrations and head losses.

20 Furthermore, a multiplicity of transverse fins (21) is provided inside the chamber, for mechanical reinforcement between two walls and for stirring the fluid.

25 The fins may be of various shapes depending on the applications and the desired effects, for example a laminar effect (figure 8) or a turbulent effect (figure 9).

30 The shape, size and cross section of the fins depend on the amount of heat to be removed and on the requirements due, for example, to the mechanical stresses: join radius between the fins and the faces of  
35 the layer, etc.

According to the invention, the follower layer (15) can be broken down into unitary heat exchange cells (22)

for the purpose of mathematically modeling all of the heat exchanges undergone or transmitted by the mold during production of a part.

5 A unitary exchange cell (22) is illustrated individually in figure 10 and shown diagrammatically on one of the strata ( $7_{i+1}$ ) in figure 7b.

10 The various characteristic parameters of this virtual base cell (22) are used, in accordance with the invention, for mathematically calculating in an optimum manner the dimensions of the part and of the circuit before they are produced, by writing, within the competence of a person skilled in the art, heat balance 15 equations using analytical models and/or multiphysical numerical simulations.

According to two more embodiments, shown in figures 11 and 12, and in order to limit the thermal conduction 20 toward the sides (convective losses with the outside) and/or toward the bottom (conductive losses with the machine frame) of the mold, said mold includes, respectively, a plurality of isolating follower channels (23) (figure 11) and, parallel to them, an 25 isolating follower layer (24) (figure 12), these also being produced during the micromilling step of the STRATOCONCEPTION and designed in the same way as the regulating follower channels (2) or the regulating follower layer (15).

30 The isolating channels (23) and the isolating layer (24) are located at a constant or variable distance from the regulating follower layer (15) and on the outside of the latter, that is to say between the 35 follower layer (15) and the outside of the mold (the side and bottom faces).

The dimensions and the cross sections of the isolating

channels (23) and the isolating layer (24) depend on the isolation to be provided and are also obtained from multiphysical numerical simulations. For example, they are thicker when they are close to the machine platens than when they are close to the external faces, since the losses by conduction into the platens are greater than those by natural convection as regards the external faces.

10 The isolating channels and layers form either an active isolation or secondary regulation, or a passive isolation if they are filled with an insulating material.

15 Figure 13 shows schematically a method of filling with an insulating resin (25) in a vacuum chamber (26) for passive isolation.

20 A volume of resin (25), which is greater by a few percent (owing to shrinkage) than the internal volume of the channels or the layer to be filled, is introduced under an air vacuum into said internal volume. A telltale (27) is used to ensure complete filling.

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Figure 14 shows an example of an active thermal regulating device for the regulating fluid circulating in a follower layer (15) isolated externally by an isolating layer (24).

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The cooling fluid (28) at a temperature ( $T_1$ ) is sent by a pump (29) into the chamber (20) of the follower layer (15). A solenoid valve (30) controlled by a regulator (31) mixes, if necessary, a colder liquid (32) at a 35 temperature ( $T_2$ ) with the cooling liquid (28) depending on the measured difference between a temperature ( $T_3$ ) measured in the mold region lying between the molding surface (3) and the reference temperature ( $T_4$ ) chosen

for the regulation.

Moreover, to obtain a molding tool suitable for withstanding the mechanical stresses, provision is  
5 made, during the bonding of the strata, for there to be a mechanical brace, an application of mechanical adhesive on the regions extending from the channels as far as the outside of the mold, and an application of adhesive with a predetermined thermal conductivity on  
10 the regions extending from the cooling circuits and as far as the molding surface. The term "cooling circuit" is understood to mean both the network of channels and the layer construction.

15 In general, the method ensures that the strata are held in place in a technically and economically suitable manner for the intended application by the choice of technique for assembling the strata, namely adhesive bonding, brazing, screwing or the like.

20 A method according to the invention makes it possible to make the regulation of the tools comply with the requirements of the parts to be produced, allowing very fine regulation in the case of high-performance parts,  
25 or else active regulation in the case of consumer parts. We thus:

- optimize the regulation of the tools;
- improve the productivity of the tools;
- optimize the mechanical strength of the parts  
30 produced;
- reduce their geometrical distortion;
- reduce their internal stresses due to cooling;
- reduce their internal stresses due to filling;
- reduce the thermal inertia of the tools; and  
35
- reduce their weight.

Furthermore, it is possible to produce bulk or crude items (preformed or otherwise) dedicated to a part,

with the optimized system of channels already produced.

Each stratum is seen as an independent solid, thus one is concerned only with the heat that is supplied to it,  
5 and the channel is dimensioned in this way.

The hotspots may therefore be treated with greater care.

10 Any imbalance in the cooling, due to the mold/material contact conditions and/or to difficulties of gaining access between the die and the punch, may be eliminated.

15 At any point in the impression, heat removal is optimized.

It is possible to achieve uniform cooling, (in terms of flux, temperature, heat transfer coefficient) over the  
20 entire surface of the part, while still ensuring a cooling time adjusted to the shortest possible, or minimum cooling time, while nevertheless limiting the residual stresses and the deformations in the part.

25 Thanks to the low inertia of the mold, it is possible to control the cooling dynamically. Thus, it is possible to heat the mold, after ejection of the part, to keep it hot until the end of the filling operation and then to cool it. Mold cooling is started slightly  
30 before the end of filling, this depending on the reaction time of the tool itself (very short time thanks to the reduced inertia of such tools).

35 By improving the filling operation, its duration is shortened, making it easier for the polymer to flow, and the level of internal stresses in the injection-molded part is also reduced.

The combination of optimized cooling with dynamic control of the thermal regulation of the mold allows the cycle time to be reduced by decreasing the filling time and the cooling time.

5

This combination also allows the internal stresses in the injection-molded parts to be considerably reduced - this reduces their distortion and their post-shrinkage, increases their dimensional quality and improves their 10 aging behavior.

Irrespective of the type of cooling desired, the dimensional, structural and mechanical qualities of the injection-molded parts are improved, whether these be 15 high-performance products, attractive products or consumer products.

The heat transfer is optimized by cell modeling, charts and simulation means being used to choose each 20 regulating parameter.

The positioning of the fins and their dimensions influence the heat transfer, the mechanical strength of the tools, and the control of turbulence (header 25 losses, etc.). This positioning must therefore be studied and optimized using numerical simulation and optimization tools.

The design of the feed headers (18) and outlet headers 30 (19) is a key point for regulating fluid flow control. This design is also simulated and numerically optimized (for example by providing wider or more numerous nozzles (34) at the necessary points) (see figure 6).

35 The time needed to bring the tools into service (to temperature) is shortened. Their weight is also reduced.

The mold has a low thermal inertia. This is due to thermal and mechanical optimization of the wall thickness between the follower layer and the molding surface, and may also be increased by the isolating 5 action of the second layer, if necessary. The volume to be regulated is thus optimal.

This minimal inertia gives the tools a greater production capacity. This is because not only is the 10 regulating time optimized but the tool returns more rapidly to its initial conditions in order to start a new cycle.

Of course, the examples and/or applications described 15 above do not limit the invention.

In particular, the invention extends to many other known fields of application, namely metal foundry work, the building industry, the printing industry or others. 20

In point of fact, depending on the requirement, the fluid chosen may be a liquid, a gas or a powder, and may be used, for example, for the purpose of heat exchange, for isolation, for marking, for plugging 25 and/or for assembly and/or rigidification by solidification (or other processes, etc.).

Moreover, for the sake of simplification and clarity a break-down operation has been performed in parallel 30 planes, but this is in no way limiting, and it may also be performed in warped surfaces.

It should also be mentioned that the breaking-down of the circuit or circuits is tied to that of the part, in 35 the sense that this may be identical, or tied by a mathematical relationship.

Finally, the term "cell" may have been used in the text

with various qualifiers, but intellectually it denotes the same concept.